A 2-Year Small Grain Interval Reduces Need for Herbicides in No-Till Soybean

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This study measured weed interference in soybean and corn as affected by residue management tactics following a sequence of oat and winter wheat. Residue management tactics compared were conventional tillage, no-till, and no-till plus cover crops. Treatments were split into weed-free and weed-infested conditions; prominent weeds were green and yellow foxtail and common lambsquarters. Grain yield of soybean did not differ between weed-free and weed-infested conditions with no-till, whereas weeds reduced yield 25% in the tilled system. Corn responded inconsistently to treatments, with more than 40% yield loss due to weed interference in 1 yr with all treatments. Cover crops did not improve weed management compared with no-till in either crop. Seedling emergence of the weed community differed between tillage and no-till; density of weed seedlings was fivefold higher with tillage, whereas seedling emergence was delayed in no-till. The initial flush of seedlings occurred 2 to 3 wk later in no-till compared with the tilled system. Designing rotations to include cool-season crops in a no-till system may eliminate the need for herbicides in soybean to manage weeds.

Nomenclature: Common lambsquarters, *Chenopodium album* L.; green foxtail, *Setaria viridis* (L.) Beauv.; yellow foxtail, *Setaria glauca* (L.) Beauv.; corn, *Zea mays* L.; oat, *Avena sativa* L.; soybean, *Glycine max* (L.) Merr.; wheat, *Triticum aestivum* L.

Key words: Alternative weed control, cool-season crops, corn, cover crops, cultural weed management, no-till, residue management.

The corn–soybean rotation has been the prominent rotation in the north central United States for several decades. Some producers, however, are concerned about long-term sustainability of this system because of soil degradation (Larson 1981; Triplett and Dick 2008) and environmental contamination by agricultural inputs (Miller 2008). Kirschenmann (2007) also expressed a concern about the system's dependence on external energy sources. Another issue with the corn–soybean rotation is that crop management requires extensive inputs to manage pests. Weeds are a continuous obstacle to crop production (Gibson et al. 2006), whereas crop yield is often reduced by corn rootworm (*Diabrotica* spp.) and soybean cyst nematode (*Heterodera glycines* Ichinohe) (Levine et al. 2002; Miller et al. 2006). Pesticide resistance adds a further economic burden for producers (Kropff and Walter 2000).

Some concerns, such as soil degradation and energy use, are being addressed by conservation tillage (Phillips et al. 1980; Triplett and Dick 2008). However, pest management in conservation tillage systems remains a major production cost. Pest management would be easier if other crops were added to the corn–soybean rotation (Anderson et al. 2006; Lewis et al. 1997), but producers are concerned that alternative crops will be of lower value than corn or soybean, consequently reducing economic returns.

Producers in Europe, facing similar issues with crop rotations and pest management, were able to address this concern of low-value crops with the use of multifunctional rotations (Vereijken 1992). The multifunctional approach designs rotations to accrue numerous benefits from crop diversity such as increased yields, improved pest management, and more efficient nutrient cycling. A 15-yr on-farm trial showed that adding small grains to rotations comprised of high-value vegetable crops enabled producers to reduce fungicide and insecticide inputs 90% (Lewis et al. 1997). Additionally, herbicide and fertilizer inputs were reduced almost 30%. Lower input costs along with higher yields due to the rotation effect led to similar net returns with multifunctional rotations compared with the conventional vegetable rotations. Maximum benefits with this approach occurred when at least four different crops were included in rotations (Boller et al. 2004).

Multifunctional rotations are also successful in the semiarid Great Plains. Rotations including a diversity of crops increase net returns, reduce pest infestations, and restore soil health compared with the conventional winter wheat–fallow rotation (Anderson 2009). Net returns improve because of increased land productivity, but another contributing factor is that weed management costs were 50% less than the conventional rotation (Anderson 2007a). Rotations with crop diversity provide more opportunities for producers to disrupt weed population growth with cultural tactics. The need for herbicides is reduced in diverse crop rotations because weed community density declines across time.

The design of crop rotations can be a critical factor in weed management (Anderson 2004; Bastiaans et al. 2000). For example, three long-term rotation studies were started in the semiarid Great Plains in the early 1990s. Weed management was based on best-management practices, yet weed community density varied eightfold among rotations after 10 yr (Anderson 2008). In all studies, the lowest weed density occurred in rotations comprised of two cool-season crops followed by two warm-season crops. The 2-yr interval with similar seasonal crops accentuates the natural loss of weed seeds in soil by minimizing seedbank replenishment of weeds with contrasting life cycles, such as warm-season weeds during the cool-season crop interval.

DOI: 10.1614/WT-09-030.1

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Table 1. Dates of operations for establishing and harvesting oat, winter wheat, corn, and soybean at the two sites. Each site was conducted over a 3-yr interval. CC refers to cover crops established preceding corn or soybean.

		Site 1		Site 2	
Crop	Operation	Year	Date	Year	Date
		2003		2004	
Oat	Planting		April 1		April 3
	Harvest		July 31		July 28
Winter wheat	Planting		September 15		September 9
		2004		2005	
Winter wheat	Harvest		August 2		July 27
Hairy vetch (CC)	Planting		August 19		August 23
Rye (CC)	Planting		September 8		September 15
		2005		2006	
Corn	Planting		May 13		May 15
	Harvest		October 21		October 25
Soybean	Planting		May 25		May 26
	Harvest		October 11		October 8

We are interested in exploring multifunctional rotations in eastern South Dakota, where corn–soybean is the prominent rotation. Our initial goal is to determine impact of crop diversity on weed management in corn and soybean. Therefore, this study assessed weed interference in corn and soybean as affected by residue management following 2 yr of cool-season crops. Our objective was based on two hypotheses. First, 2 yr of cool-season crops with no-till should reduce seedbank density and, subsequently, seedling emergence of warm-season weeds in the third year (Anderson 2008). An earlier study at this location showed that cool-season crops such as winter wheat along with no-till accelerates the natural decline of common sunflower (*Helianthus annuus* L.) seed in soil, compared with corn or soybean in a tilled system (Anderson 2007b). Second, preserving crop residues on the soil surface will suppress weed seedling establishment in corn or soybean (Teasdale 1996; Wicks et al. 1994). We speculated that combining these two factors may reduce the need for herbicides in corn or soybean because of lower weed density.

Materials and Methods

Site Characteristics. The study was established on a Barnes clay loam (Calcic Hapludoll) near Brookings, SD. The soil contains approximately 3% organic matter and soil pH ranges from 6.8 to 7.2. Average yearly precipitation (84-yr record) is 537 mm, with May and June receiving the highest rainfall. The study sites were established in soybean stubble. Previous to the study, the recent history of the sites was corn–soybean in a tilled system; tillage consisted of chisel plowing annually.

Treatments and Study Design. The experiment involved a 3-yr sequence of oat–winter wheat–corn or soybean (Table 1). Our paper reports the evaluation of treatments established in winter wheat stubble on crop productivity and weed interference with corn or soybean in the third year. The 3-yr sequence was started in 2003; a second site was established in an adjacent field with oat planted in 2004.

The site was bulk cropped to oat and winter wheat in years 1 and 2, respectively, with no tillage occurring from soybean harvest until after winter wheat harvest when residue management treatments were established. 'Jerry' oat at 90 kg/ha and 'Harding' winter wheat at 120 kg/ha were planted with a double-disk drill, resulting in minimal soil disturbance; row spacing was 19 cm. Nitrogen as ammonium nitrate was applied during the tillering stage of both crops based on a yield goal of 2,400 kg/ha for oat and 4,500 kg/ha for winter wheat. A starter fertilizer of 17 kg N, 43 kg P, and 16 kg K/ha was applied with winter wheat seed. A few plants of common lambsquarters were present in oat (< 1 plant/20 m^2) but none established in winter wheat. Herbicides were not applied to either crop. Weeds present after oat harvest were controlled with glyphosate applied at 0.8 kg ae/ha prior to winter wheat planting. Stubble height after winter wheat harvest ranged from 30 to 40 cm. Quantity of crop residue produced by winter wheat was estimated at crop maturity by harvesting six 1-m^2 samples randomly located in the bulk field and weighing residue quantity remaining after threshing the grain. Averaged across both sites, winter wheat produced approximately 5,450 $\pm$ 625 SD kg of residue/ha.

Three residue management treatments were established after winter wheat harvest. One treatment consisted of tillage with a chisel plow in early August, followed by disking in April of the next year to prepare a seedbed (Table 1). A second treatment, no-till, consisted of one application of glyphosate at 0.8 kg/ha to control established weeds and prevent seed production in the fall. A third treatment included cover crops with no-till (hereafter referred to as cover-crop treatment). Hairy vetch (*Vicia villosa* Roth) at 40 kg/ha or rye (*Secale cereale* L.) at 95 kg/ha were planted as cover crops to precede corn or soybean, respectively. Glyphosate eliminated weeds present at planting of the cover crops.

Corn, DK 42–95 RR,[1] was planted at 76,200 seeds/ha (Table 1). The planter unit had double-disk openers and a row spacing of 50 cm. Fertility levels were based on a yield goal of 8,500 kg of grain/ha; each plot received 120 kg N, 30 kg P, and 50 kg K/ha. A band application of 10 kg N + 30 kg P + 50 kg K/ha as a liquid formulation was applied 5 cm to the side of the seed row and 5 cm deep with a single coulter disk. The remainder of N fertilizer (110 kg N/ha) was applied broadcast as ammonium nitrate when corn had six leaves fully exposed.

Soybean, 'Pioneer 91B91' RR,[2] was planted at 395,000 seeds/ha with the same planter unit used for corn. A starter fertilizer of 17 kg N, 43 kg P, and 16 kg K/ha was applied 5 cm to the side of the seed row and 5 cm deep; no further N fertilizer was applied.

The experimental design was a two-way factorial arranged in a randomized complete block design with six replications; crop and residue management treatments were the main factors. Plot size was 7 m by 20 m. An additional factor of weed management was established by randomly splitting each plot into weed-free and weed-infested subplots. All plots were sprayed with glyphosate at 0.8 kg/ha at planting to eliminate existing weeds. Weeds in corn were controlled in the weed-free subplot by a preemergence application of *S*-metolachlor at 1.5 kg ai/ha, followed by one application of glyphosate postemergence. Weeds were controlled in weed-free soybean by one postapplication of glyphosate and hand removal of any remaining weeds. The rye cover crop was controlled by glyphosate applied on the day of soybean planting, whereas hairy vetch was controlled on the day of corn planting by mixing 2,4-D at 0.4 kg ae/ha with glyphosate. Biomass production of cover crops was estimated by harvesting a 1-m^2 sample from the weed-free subplot in each replication. Rye produced 2,350 ± 470 SD kg/ha and hairy vetch produced 1,480 ± 360 SD kg/ha, based on weight after 5 d of air drying at 60 C.

Crop and Weed Data Collection. Plant stand, plant height, and tasseling were assessed in weed-free subplots. Plant density of corn was recorded in randomly selected 3-m sections of two corn rows and plant height was measured on six random plants in each plot 8 wk after crop emergence (WAE). Date of tasseling was determined by evaluating six plants per plot on a daily basis; tasseling was defined as the time at which four of the six plants had tassels fully emerged from the last corn leaf and ear silks were visible. Date of tasseling was expressed as days after July 1. Grain yield was determined by harvesting 4 rows 10 m long in each subplot. Reported yields were adjusted to 15.5% moisture level.

Soybean density was recorded in 1-m sections of three rows randomly located in each weed-free subplot, whereas plant height was assessed at six random locations in each plot, with three measurements at each location. These data were collected in the weed-free plots 8 WAE. Grain yield was determined by harvesting 4 rows 10 m long in each subplot. Reported yields were adjusted to 13% moisture level.

Seedling emergence of the weed community was recorded weekly in a 0.5-m^2 quadrat randomly located in each weed-infested subplot. Counting started on May 15 and continued until July 17; after the weekly counting, seedlings were removed by hand. In addition to the weed emergence quadrates, weed infestation in corn and soybean was also assessed in two randomly placed 0.5-m^2 quadrats 7 WAE. All weeds in the quadrat were harvested to determine species, density, and fresh weight of weeds.

Statistical Analysis. Data were initially examined for homogeneity of variance among years,[3] and then subjected to analysis of variance for a randomized complete block design to determine treatment effects and possible interactions among treatments and years. Data for soybean and corn were analyzed separately because different N fertility management confounded the interaction between crop and weed interference. Main effects and interactions were considered significant at $P \leq 0.05$; treatment means were separated with Fisher's Protected LSD at the 0.05 level of probability. Where data were collected from more than one quadrat within a subplot, data were averaged before analysis.

The seasonal emergence of the weed community for each residue management treatment was characterized by converting weed seedling density per week to a percentage of the total seasonal emergence (May 15 to July 17). Data were averaged across replications for crops and years, with emergence curves developed by cubic spline interpolation.[4] Weed community data collected 7 WAE were averaged across quadrats within a plot, and analyzed for corn and soybean separately.

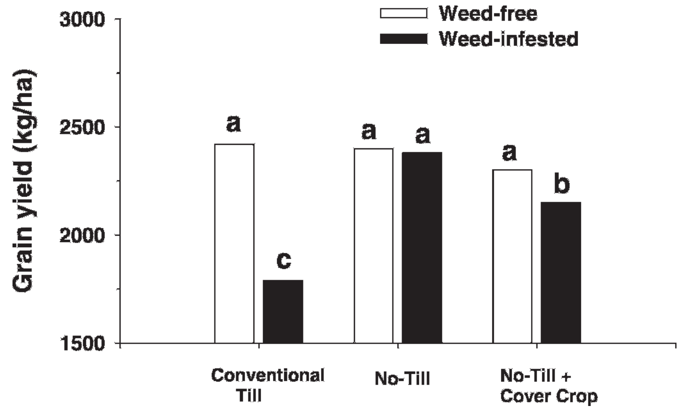

Figure 1. Grain yield of soybean as affected by residue management in winter wheat stubble. Data are averaged across years. Bars with the same letters are not significantly different as determined by Fisher's Protected LSD (0.05).

Results and Discussion

Weed Community. The prominent weed species at the sites were warm-season weeds such as green foxtail, yellow foxtail, common lambsquarters, redroot pigweed (*Amaranthus retroflexus* L.), common sunflower (*Helianthus annuus* L.), and buffalobur (*Solanum rostratum* Dun.). In both years, the foxtail species and common lambsquarters comprised more that 85% of the total seedlings observed.

Soybean Production. Statistical analysis indicated that an interaction did not occur between treatments and years; therefore, data were averaged across years. Grain yield did not differ among residue management tactics in weed-free conditions (Figure 1). Weeds reduced grain yield 25% in the tillage treatment, but no yield loss occurred with the no-till system. Weed community density 7 WAE was 51 plants/m^2 in the tilled system, but only 8 plants/m^2 in no-till (Table 2). Weed fresh weight differed more than eightfold between tilled and no-till treatments. Yield in the cover crop treatment was less in the weed-infested subplot compared with weed-free conditions (Figure 1). Weed density and biomass did not differ between no-till and cover crop treatments

Table 2. Weed community density and biomass (fresh weight) for soybean and corn, averaged across sites, and agronomic data for corn in 2005 as affected by tillage and cover crop treatments. Means within a column followed by an identical letter are not significantly different as determined by the Fisher's Protected LSD (0.05). Weed community data were collected 7 wk after crop emergence and corn data collected 8 wk after crop emergence.

	Weed community						
	Soybean		Corn		Corn (2005)		
Treatment	Density	Biomass	Density	Biomass	Population	Height	Tasseling
	plants/m^2	g/m^2	plants/m^2	g/m^2	plants/ha	cm	days after July 1
Tillage	51 a	650 a	69 a	1480 a	71,250 a	165 a	21 b
No-till (NT)	8 b	80 b	22 b	270 c	72,060 a	150 b	26 b
NT + cover crop	7 b	50 b	30 b	575 b	62,700 b	147 b	29 a

(Table 2); thus we attribute yield loss in the cover crop treatment to the additive effect of resource use by rye before planting soybean plus competitive effects of weeds. Soybean plant density and height 8 WAE was not affected by residue management (data not shown).

One factor contributing to yield differences among treatments was that seedling emergence of the weed community differed among residue management tactics (Figure 2). The total number of seedlings emerging in permanently marked quadrats in the first 7 wk of the growing season was fivefold higher after tillage compared with no-till. Furthermore, seedling emergence was delayed in no-till; the initial germination flush was 2 to 3 wk later, which provided an additional advantage for soybean in competing with weeds. Emergence patterns were similar between no-till and the cover-crop treatment (data not shown); this trend agrees with the lack of difference in weed densities recorded at 7 WAE (Table 2). All weed-infested plots were sprayed with glyphosate at planting, but weed density was low in the no-till treatment at this time (less than five plants in the entire plot). Applying glyphosate at planting likely would not have been necessary to prevent yield loss by weeds in no-till.

Corn Production. Statistical analysis indicated that treatment effects varied between years; therefore, data are shown separately for each year. In the first year (2005) with weed-free conditions, corn yielded the highest in the tilled system, whereas yield was 12 and 40% less with no-till and cover crop treatments, respectively (Figure 3A). The no-till and cover-crop treatments suppressed corn growth, as corn height 8 WAE with the no-till and cover-crop treatments was 10% shorter than corn in the tilled treatment (Table 2). We attribute this growth suppression to cool and wet conditions during seedling growth. Vyn and Hooker (2002) observed similar growth suppression in Ontario; they identified allelopathic compounds from wheat. The compounds' toxicity to corn was accentuated in these environmental conditions. Corn tasseling was also delayed 5 to 8 days in the no-till and cover-crop treatments. A second factor of yield loss with the cover-crop treatment was that plant density was almost 15% less compared with the other two treatments (Table 2). Hairy vetch apparently interfered with corn seedling establishment to reduce corn density, which has occasionally been observed in other studies (Snapp et al. 2005; Teasdale 1996). Weed interference reduced corn yield in all residue management treatments more than 40% compared to weed-free yield with tillage (Figure 3A).

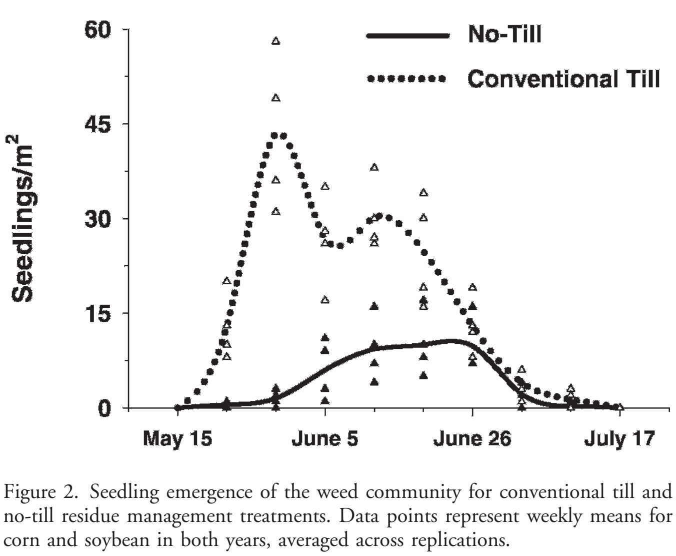

Figure 2. Seedling emergence of the weed community for conventional till and no-till residue management treatments. Data points represent weekly means for corn and soybean in both years, averaged across replications.

In 2006, the highest yields in weed-free conditions occurred with the tillage and no-till treatments (Figure 3B). However, weed interference reduce yield 43% with tillage but only 15% in no-till. This yield response reflects differences in weed establishment and growth between residue management systems. Averaged across years, weed density in no-till was only 22 plants/m^2, contrasting with 69 plants/m^2 in the tilled system (Table 2). Biomass of the weed community was nearly sixfold higher with tillage. As noted earlier (Figure 2), weed seedling emergence was also delayed in no-till, which aided corn in tolerating weeds. Corn yielded less in the cover-crop treatment in weed-free conditions, which we attribute to resource use by hairy vetch. Suppression of weeds by the cover-crop treatment led to higher yield when weeds were present in 2006 compared with the conventional till treatment (Figure 3B). However, corn yield was less with a cover crop compared to no-till in weed-free conditions because approximately 5% of hairy vetch plants escaped control by glyphosate + 2,4-D at planting. In both years, plants that survived the herbicide application produced considerable biomass (Table 2).

Even though there was not a treatment-by-year interaction for weed biomass 7 WAE (Table 2), we attribute higher yield loss in the first year with weed-infested no-till and cover-crop

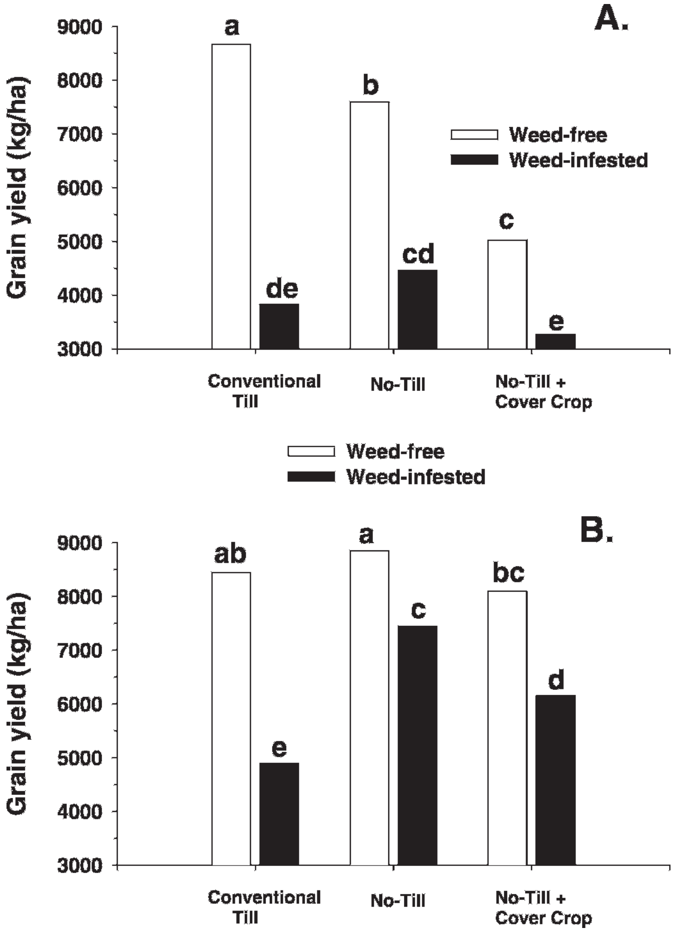

Figure 3. Grain yield of corn as affected by residue management in winter wheat stubble: (A) 2005, (B) 2006. Bars with the same letters are not significantly different as determined by Fisher's Protected LSD (0.05).

treatments (Figure 3A and B) to suppressed canopy development of corn. Weed growth likely was greater after the 7 WAE assessment in the first year because of reduced corn competition. In 2006, corn density, plant height, and date of tasseling were not affected by residue management tactics (data not shown). Also, we did not observe 2,4-D injury to corn in the cover-crop treatment in either year.

Implications for Weed Management. The combination of cool-season crops and residue management with no-till almost eliminated weed interference in soybean. This management approach, however, was inconsistent in corn. The minimal weed interference in no-till soybean reflects low weed seedling emergence during the 7 wk after emergence; seedling emergence was fivefold higher in conventional till compared with no-till (Figure 2). This difference in emergence may seem an anomalous trend, but a similar contrast between no-till and tilled rotations occurred in the semiarid Great Plains; weed seedling emergence was eightfold higher in a tilled system compared with no-till in the third year of a study where weed seed entry was prevented in all years (Anderson 2007a). Similarly, common sunflower seedling emergence was sevenfold higher in the year following a corn–soybean sequence with tillage compared with a no-till canola (*Brassica napus* L.)–winter wheat sequence (Anderson 2007b). These studies indicate that survival of weed seeds across time is reduced by no-till systems and rotations that include cool-season crops.

We included the cover-crop treatment in this study to determine if additional crop residue would enhance suppression of weed establishment by winter wheat residue. The lack of improved weed control with cover crops indicates that the combination of cool-season crops, no-till, and winter wheat residue on the soil surface was sufficient to reduce weed seedling density and almost eliminate interference in soybean.

Conservation tillage protects soil in cropping systems, but scientists are seeking to enhance its benefit by integrating crop diversity with no-till and residue management to develop conservation agriculture (Food and Agriculture Organization—United Nations [FAO] 2008; Hobbs 2007). The goal of conservation agriculture is to merge soil health restoration and environmental protection with land productivity and economics. Multifunctional rotations helped producers develop conservation agriculture in the Netherlands (Vereijken 1992) and the semiarid Great Plains (Anderson 2009). This approach may also help producers growing corn and soybean to achieve conservation agriculture.

Diversifying the corn–soybean rotation will gain other benefits along with weed management, such as reducing infestation levels of soybean cyst nematode and corn rootworm (Levine et al. 2002; Miller et al. 2006). Also, crop diversity can increase grain yield of corn and soybean. For example, corn yields 15 to 40% more in a winter wheat–corn–soybean rotation compared with corn–soybean (Katsvairo et al. 2002; Zhang et al. 1996). The yield gain in both studies was attributed to winter wheat's improving soil structure and health.

Sources of Materials

[1] Corn, DeKalb Seed, Monsanto Agriculture Products Co., St. Louis, MO 63167. RR is an abbreviation for glyphosate-resistant hybrid.

[2] Soybean, Pioneer Hi-Bred Seed, DuPont Co., Wilmington, DE 19801. RR: glyphosate-resistant.

[3] Statistix Analytical Software, Tallahassee, FL 32317.

[4] Sigma Plot, Jandel Scientific, Point Richmond, CA 94804.

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Received March 5, 2009, and approved May 15, 2009.